BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B70 10029

SUBJECT: An Analysis of the Scientific Objectives and Proposed Landing Sites in the Hadley-Apennine Region
Case 340

DATE: October 13, 1970

FROM: J. W. Head

ABSTRACT

The possible scientific objectives at the Hadley-Apennine region are outlined and include the Apennine Mountains, Hadley Rille, mare material, Hadley C crater, volcanic landforms associated with the mare, and secondary crater clusters. Each objective is examined in terms of where in the Hadley-Apennine region it might be best achieved, based on different interpretations of the origin of these various features. Five landing points are evaluated in terms of the ability to achieve the scientific objectives both on a rover and a walking mission.

(NASA-CR-111020) AN ANALYSIS OF THE SCIENTIFIC OBJECTIVES AND PROPOSED LANDING SITES IN THE HADLEYAPENNINE REGION (Bellcomm, Inc.) 19 p

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MEMORANDUM FOR FILE

I. GENERAL

Hadley-Apennine

The Apennine Mountains rise up to 2 km above the relatively young mare surface of Palus Putredinis and might contain material exposed during excavation of the Imbrium basin (Figure 1). Sampling of such Apenninian material might provide ancient rocks whose origin predates both the formation and the filling of the major mare basins. Rima Hadley is a V-shaped lunar sinuous rille which parallels the Apennine Mountain front along the eastern boundary of Mare Imbrium. The rille originates in an elongate depression in an area of associated volcanic domes and generally maintains a width of about 1 km and a depth of 200-300 meters until it merges to a second rille approximately 75 km to the north. The origin of sinuous rilles such as Rima Hadley is enigmatic but probably involves some type of fluid flow and/or collapse. Thus, the study of the process of sinuous rille formation may yield data on the history of lunar volatiles.

II. DETAILED SCIENTIFIC OBJECTIVES OF THE HADLEY-APENNINE REGION

1. Apennine Mountains

The Apennine Mountains form part of the southeastern boundary of Mare Imbrium and are believed to have been formed at the time of origin of the Imbrium basin. The Apennines are analogous to the Cordillera Mountains in the fresher Orientale basin on the western limb of the lunar frontside. Study of these analogous regions in the Imbrium and Orientale basins suggests that the impact event ultimately responsible for the formation of the multi-ringed structures also resulted in deposition of a thick blanket of ejecta around and on the rim of these basins. This ejecta would mantle large areas around the Imbrium basin, thinning away from the basin interior, and overlying preexisting topography probably similar in morphology to highland regions of the moon. The basinward scarps of both the Apennine and Cordillera Mountain chains probably represent fault planes along which inter-ring blocks subsided after relaxation of the initial compression assumed to be associated with the event (Figure 2). The material exposed on the scarps or mountain fronts could represent a cross section of lunar crust several thousand meters thick. Several factors, however, combine to reduce the amount of ancient crustal material which might actually be exposed on the scarps.

(1) Mare flooding, subsequent to the origin of the basin and formation of the scarps, will progressively cover the lower and probably older parts of the exposed section (see Figure 3,2 b,c). Thicknesses of this mare fill at the base of the Apennine Front are uncertain but the 200-300 meter depth of Hadley Rille suggests that this figure is a minimum.

(2) A second factor concerns the ejecta thrown out of the Imbrium Basin at the time of its origin (Fra Mauro Formation). This unit forms a blanket which mantles the preexisting ancient crustal material and decreases in thickness away from the basin center. Estimates of the thickness of this blanket are plotted along with that of Orientale in Figure 4. One estimates the thickness at the Hadley-Apennine region at approximately 800 meters. Therefore, the upper $\approx$800 meters of the Apennine Front is probably composed of Imbrium basin ejecta rather than a section of in-situ pre-Imbrium crustal material (Figure 3).

(3) An additional possibility suggests that no section of in situ pre-Imbrian crustal material exists along the Front. In this case, the Fra Mauro Formation would have blanketed the front area and would have been deposited subsequent to the formation of the front. Evidence for this possibility can be seen by looking at the relatively fresher Orientale Basin, in which the Cordillera Mountain scarp (analogous to the Apennine Mountain Front) appears to be draped by the Orientale ejecta blanket (Lunar Orbiter IV, 181, 3H, 2H) along many portions. The ejecta blanket is virtually continuous in the area between the outer ring (Cordillera Mountains) and the next inner ring (Rook Mountains). Therefore, an

ejecta blanket underneath the present Imbrium mare surface and draped over the Apennine Mountain Front, cannot be ruled out. In this case, the in-situ pre-Imbrian crustal material would be blanketed along the mountain front unless subsequent faulting exposed portions of it (Figure 5c).

(4) An additional possibility, and perhaps the most likely one, suggests that the Apennine Front is obscured by a talus pile consisting of mixed debris of the Fra Mauro Formation and pre-Imbrian crustal material derived from the scarp (Figure 5b). In this case, differentiation of the two units might be difficult and assignment of any material to a particular depth or portion of the crustal section on stratigraphic grounds would be virtually impossible.

In summary, a number of possible interpretations exist for the relationships along the Apennine Front, and each interpretation has varied ramifications for different parts of the Apennine area. Accepting the general model of crater ejecta distribution, Fra Mauro Formation deposited at the <u>top</u> of the Apennine Mountains in the Hadley region should have originated from deeper within the interior than material deposited at the Apollo 14 landing site. However, a talus pile derived from the complete section of Fra Mauro deposited at the front would probably consist of a mixture of material from all depths.

<u>Apennine Mountain Subdivisions</u>

(1) Apennine Mountain Front - the region directly along the frontal mountain scarp constitutes the most likely area for sampling in-situ pre-Imbrian crustal materials.

(2) Apennine Front Spurs - These features, the most prominent of which is located near the origin of Hadley Rille just south of landing point 5 (Figure 1), do not achieve the elevation characteristic of the Apennine Front scarp itself. If, in fact, they are downfaulted portions of the Apennine Front, sampling of these structures may yield only Fra Mauro Formation (Figure 6).

(3) Apennine Ridge West of Rima Hadley - This region, although physically connected with the Apennine Mountain front, may have undergone a different history than the front area itself. First, since the elevation of this structure is also lower than the front, it is more apt to be completely mantled by Fra Mauro Formation. Furthermore, the areas around the edge of this structure, such as the bench-like area to the east,

may have been obscured or covered by mare material before final settling of the lava cover. (For example see southern portion of Orientale central mare basin (NW quadrant of LO IV 195-H3] for a mare bench around probable ejecta or fall-back. This bench appears to have formed as magma evacuated the central basin causing settling and collapse.)

2. Hadley Rille

Hadley Rille is a sinuous rille originating in the vicinity of several elongate depressions near the Apennine Mountain front (Figure 1). The origin of these widespread lunar features has long been debated and has variously been attributed to flowing water, nues ardentes, tectonism, lava channels, and collapsed lava tubes. Whatever their detailed origin, they appear to be related to volcanic processes associated with mare basin filling. Investigation of Hadley Rille could shed light on the origin of these ubiquitous mare features. Since Hadley has a rather V-shaped cross section, as opposed to flat floored rilles such as Schroeters Valley and Rimae Prinz, it appears that the floor has been filled in by collapse or talus slump. The approximate slope of the side of the rille is $\sim 25°$ and it averages 250-325 m in depth. Numerous outcrops and apparently layered material are seen along and just below the rille rim. These layers may represent lava flows and interlayered regolith. Numerous large blocks have rolled to the bottom of the rille and several large boulder tracks can be seen. Examination and sampling of the rille floor in the area of intersection of the sinuous rille and the elongate depression would be extremely valuable. Examination of the rille floor elsewhere along its course would also be valuable, if access is possible. If access is not available, sampling of the rille rim and photography of the walls would be highly desirable. Optimum photographic situations for photography of the opposite side of the rille are $\leq 45°$ either side of the down sun direction. With the sun to the astronaut's back, photography of the rille side on which the astronaut is standing will produce marginal results because of sun angle and slope. Photography of either rille wall from the downsun or western side will result in pictures with low image brightness and high glare (H. W. Radin, personal communication).

3. Mare Material

The major portion of the flat terrain between Hadley Rille and the Apennine ridges consists of mare material forming an embayment into this area from Palus Putredinis to the west. This unit has been mapped as Imbrian in age. Using the method devised by Soderblom, the Hadley area mare material appears relatively younger than both Apollo 11 and 12 sites (Figure 7). Examination of high resolution photographs reveals a large number of blocky craters in the 100-250 m range, particularly in the northern part of the area, which should make sampling of this unit very easy.

4. Hadley C Crater

The origin of Hadley C Crater has been a matter of controversy for some time. Its lack of distinctive and widespread ray and secondary crater patterns, combined with its association with the mare material, sinuous rille, and apparent constructional volcanic features, has led to the suggestion that the crater might be of volcanic origin, possibly a maar. An alternate explanation suggests that the crater is of impact origin and Eratosthenian age, its ray pattern having been eroded and subdued. Ejecta from Hadley C covers the Imbrium mare material and parts of the rille, suggesting that whatever its origin, it is younger than Imbrium. Since Hadley C is approximately 5.5 km in diameter, an impact origin would imply that a considerable section of mare material was excavated. Sampling radially along the ejecta blanket could provide a spectrum of samples indicating the ages and compositional changes characteristic of mare filling. A volcanic origin for Hadley C, particularly as a maar, would suggest the possibility of samples originating in deeper regions of the lunar interior.

5. Volcanic Landforms Associated with the Mare

A wide spectrum of domes, domical hills, and associated structures exist in various places between the Apennine Front and Apennine Ridge to the west of Rima Hadley. Most of these features appear to be superimposed on the mare material and their morphology suggests that they are constructional volcanic landforms. In particular, these structures abound around the origin of Rima Hadley near the elongate depression and are also found along the Apennine Front and on the northeast bank of Rima Hadley where it turns northwest toward Rimae Fresnel. Investigation of this spectrum of landforms may provide important geochemical and age data on late stages of mare basin fill.

6. Secondary Crater Clusters

Secondary crater clusters from the Copernican age craters Autolycus and Aristillus, located approximately 150 - 300 km to the north, are widespread in this region. Examination of a cluster large enough to yield rocks from these craters could provide information about the absolute age of these Copernican events, as well as samples from another part of the Imbrium Basin.

III. Possible Landing Sites and Their Relation to Scientific Objectives

The location of several possible landing sites is shown in Figure 1 and the relationships of these to the accessibility of various scientific objectives on both riding and walking missions is summarized in Figure 8. For riding missions a maximum radius of operations of 9.5 km was accepted based on a Portable Life Support System (PLSS) failure. For walking missions, a maximum radius of operations of 3.1 was accepted based on the Buddy Secondary Life Support System (BSLSS) walkback limit.

Landing Point 1 -

Riding mission - This landing point provides ready access to the widest variety of major objectives of all the points considered. A short EVA could be devoted to any of the four major objectives just to the south of the landing point (Apennine Front material, Rima Hadley, mare material, and a secondary crater cluster). A second longer EVA could be devoted to the Apennine Front itself and a third EVA to the rille and volcanic complex several kilometers to the northwest. Although access to the rille may not be possible at this point, a bend in the rille near the landing point provides an excellent opportunity for observational and photographic studies. In addition, two craters occur in and along the edge of the rille and one of these may provide access to parts of the rille walls. A crater approximately 2 km in diameter may have excavated blocks of Apennine Front material which should be accessible to the astronauts. It appears that the features of interest at this site, particularly the Apennine Front, will be sunlit (except for parts of the rille) during all three EVA's.

Walking mission - A mission from this landing point would be able to reach all the objectives of a riding mission, with the exception of access to the volcanic landforms to the northwest.

Landing Point 2 -

Riding mission - This landing point provides access to the Apennine Ridge west of Rima Hadley, to Rima Hadley rim and possibly the wall and floor, to the mare material and to the crater Hadley C. A single EVA could be spent sampling the fresh-looking scarp several kilometers to the northwest of the landing site. As previously noted, however, the material composing this feature may have a different origin than that material available at the Apennine Front proper. A second EVA could be directed toward Hadley Rille and the crater Hadley C and would largely traverse the ejecta blanket of that crater. It is possible that access to the floor of the rille could be gained where the ejecta from Hadley C lowers the slope to the bottom of the rille. However, it is quite possible that the same ejecta which provides access to the rille could also cover large areas of the rille floor and walls. The equivocal nature of the objectives at the rille and the Apennine ridge tend to place this landing point in a lower priority.

Walking mission - A walking mission from this landing point provides access to the mare material and the outer ejecta of Hadley C. The distances to the rille rim and to the Apennine ridge appear to just exceed the 3.1 km BSLSS walkback limit.

Landing Point 3 -

Riding mission - A riding mission from this landing point could reach the Apennine Front in a single EVA. One could spend considerable time examining and sampling the area. A single EVA could also be spent investigating the complex of volcanic domes and plains to the south. Alternatively, these two objectives could be combined into a single EVA in a south-easterly direction. A second (or third) EVA could concentrate on the sinuous rille rim, particularly in the area where several craters may have excavated material from the rille wall. A traverse to the northeast along the rille rim could possibly get to the outer fringes of the Hadley C ejecta blanket (on the eastern side of the rille) but access to the rille floor would still lie several kilometers to the north.

Walking mission - From this landing point, a walking mission could reach the rille rim but the Apennine Front would lie just beyond the 3.1 km BSLSS walkback limit.

Landing Point 4 -

Riding mission - A riding mission for this landing point could provide access to the rille rim, the elongate depression associated with the rille origin, the Apennine ridge west of Hadley, mare material and associated volcanic landforms, and a possible secondary crater cluster. A single EVA could be devoted to the exploration and sampling of material from the Apennine Ridge to the west. A second EVA might concentrate on entering the elongate depression to the southwest of the landing site, while a third EVA might be spent along the rille rim and in the constructional volcanic domes and hills to the east and southeast of the site. The Apennine Ridge material is equivocal in its origin, as previously mentioned, but its proximity should allow sufficient time for detailed investigation.

Walking mission - A walking mission from this landing point would probably result in loss of access to the Apennine Ridge but one could reach the rille rim and some of the constructional volcanic units.

Landing Point 5 -

Riding mission - A riding mission from this landing point provides access to an Apennine Front spur, to the rille rim and possible blocks of wall material, and to mare material and associated volcanic landforms. The Apennine Front proper is approximately 10 km due east of the landing area. The Apennine Front spur may provide access only to the Fra Mauro Formation (Figure 6). A single EVA could be spent along the rille and in the volcanic domes to the northeast and northwest of the landing region. A second or third EVA might combine exploration of the Apennine Front spur with examination and sampling of the rille and volcanic forms to the southwest of the site.

Walking mission - A walking mission from this landing point would have access on separate EVA's to the rille rim, the Apennine Front spur, and to a mare dome structure. Probably only two of these three features could be visited.

IV. Conclusions

Based on the detailed scientific objectives in the Hadley-Apennine region and the broad operational constraints, Landing Point 1, followed by Landing Point 5, appear to offer the best chance of achieving the scientific goals of a LRV mission to this region. In addition, the scientific objectives at Landing Point 1, and to a lesser extent at Landing Point 5, are so arranged that a walking mission would still maintain an adequate chance of achieving the major scientific objectives of the mission. Although Landing Points 3 and 4 offer adequate LRV traverses, each is degraded significantly scientifically if a walking mission is undertaken.

2015-JWH-dmu

James W. Head

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Attachments
Figures 1-8

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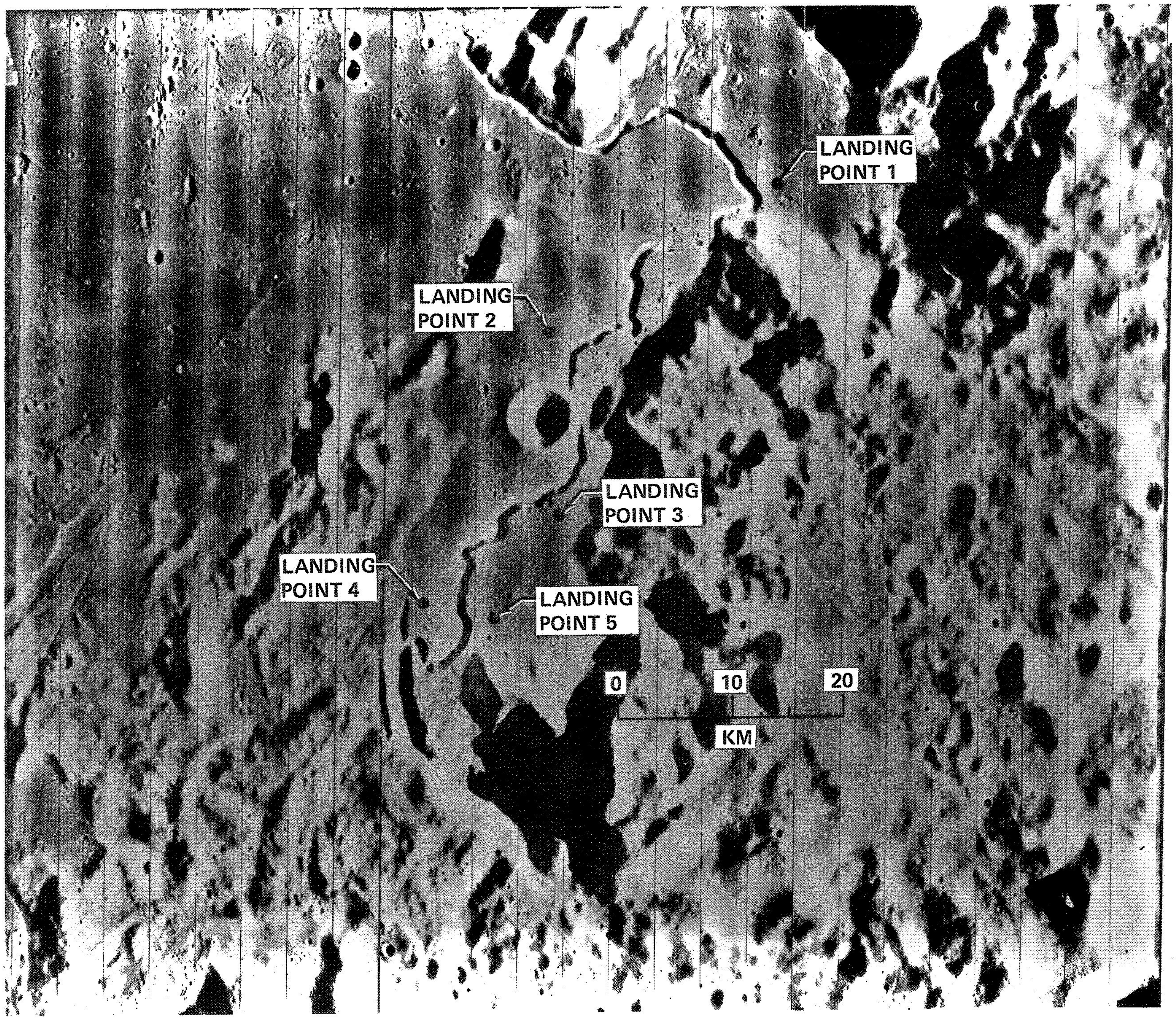
LANDING POINT 1
LANDING POINT 2
LANDING POINT 3
LANDING POINT 4
LANDING POINT 5
0
10
20
KM

FIGURE 1

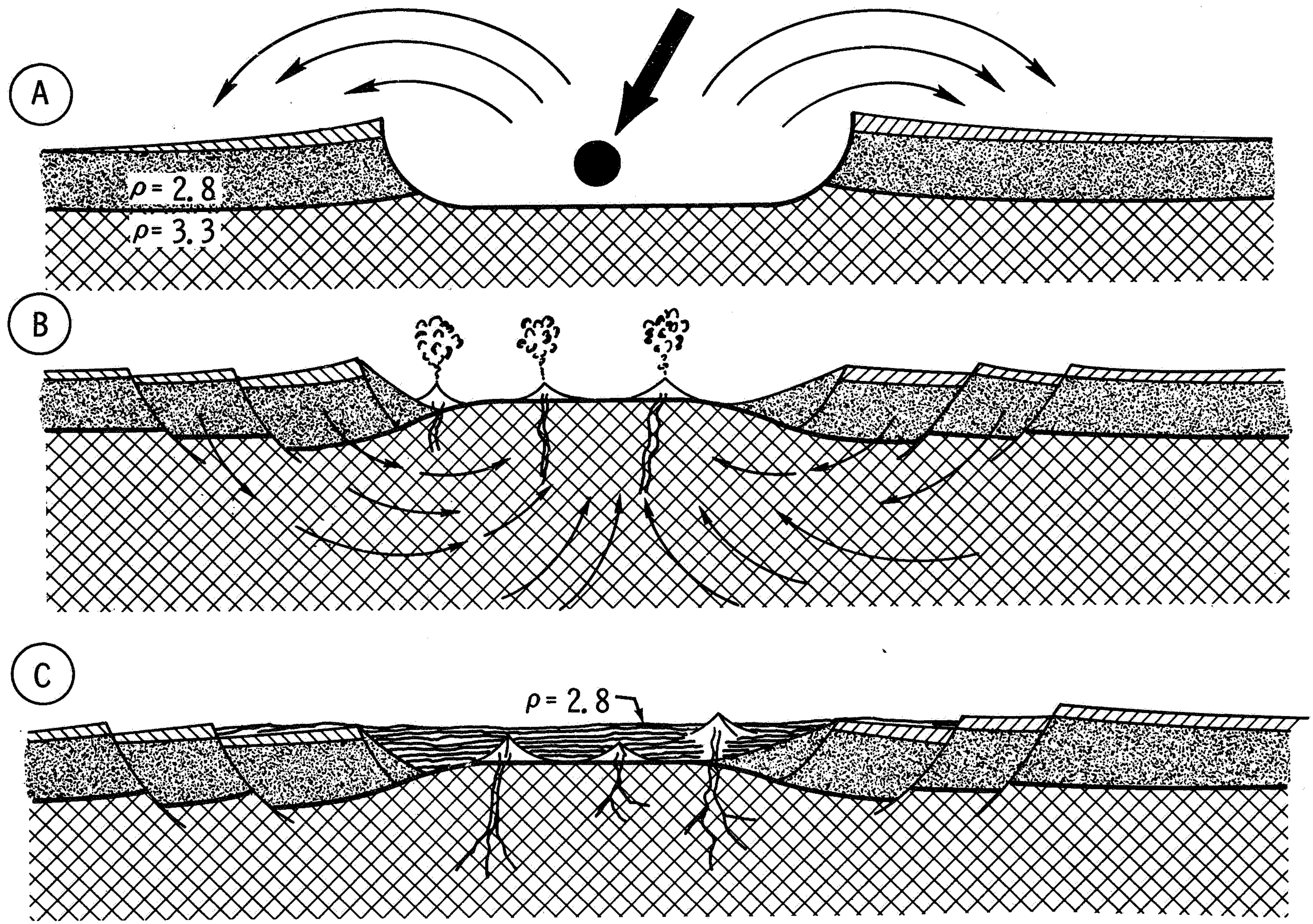

FIGURE 2 - FORMATION OF A MULTI-RINGED BASIN (AFTER WISE AND YATES)[5]

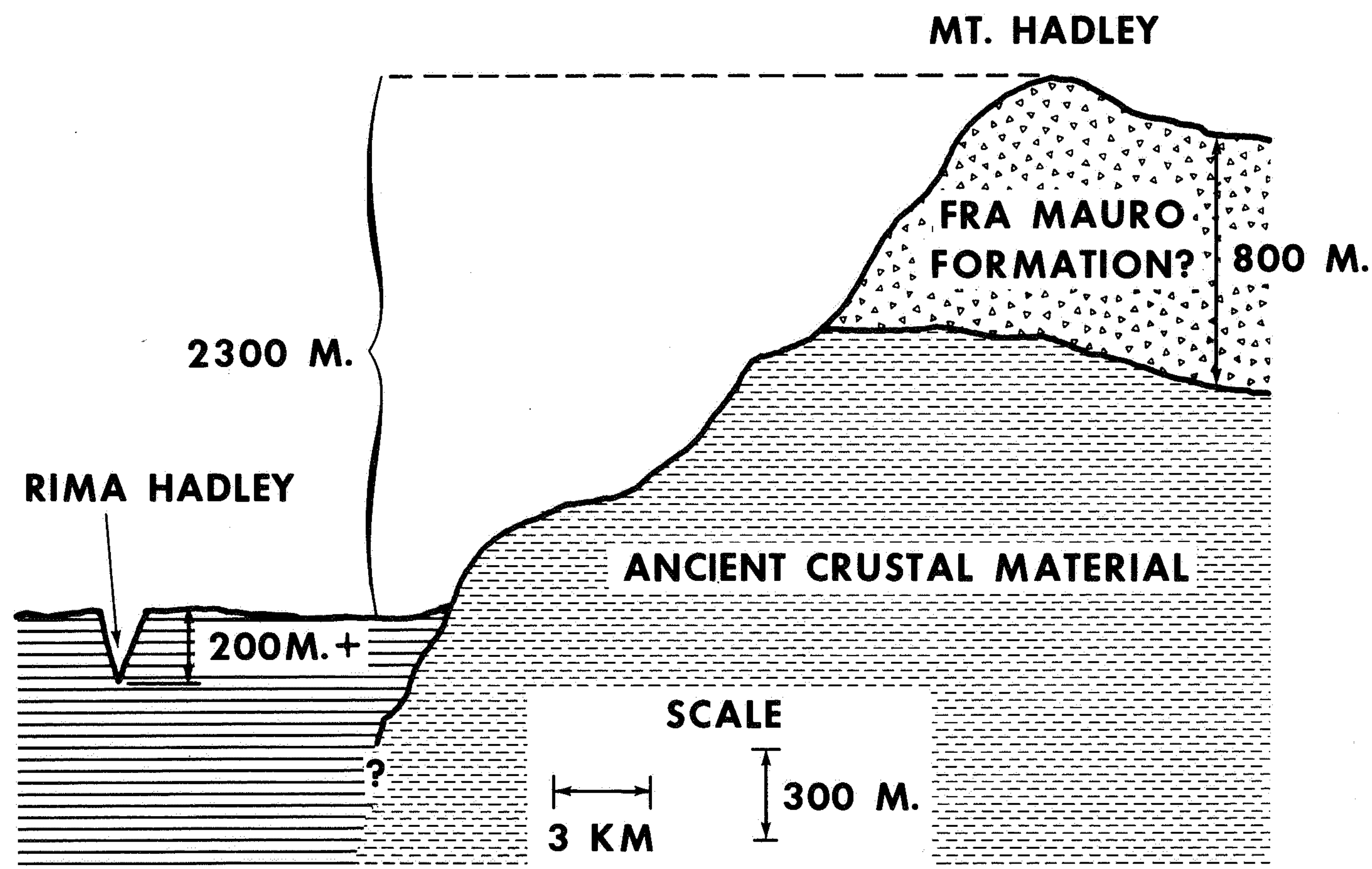

FIGURE 3 PROBABLE ELEVATIONS AND THICKNESSES ALONG THE APENNINE FRONT

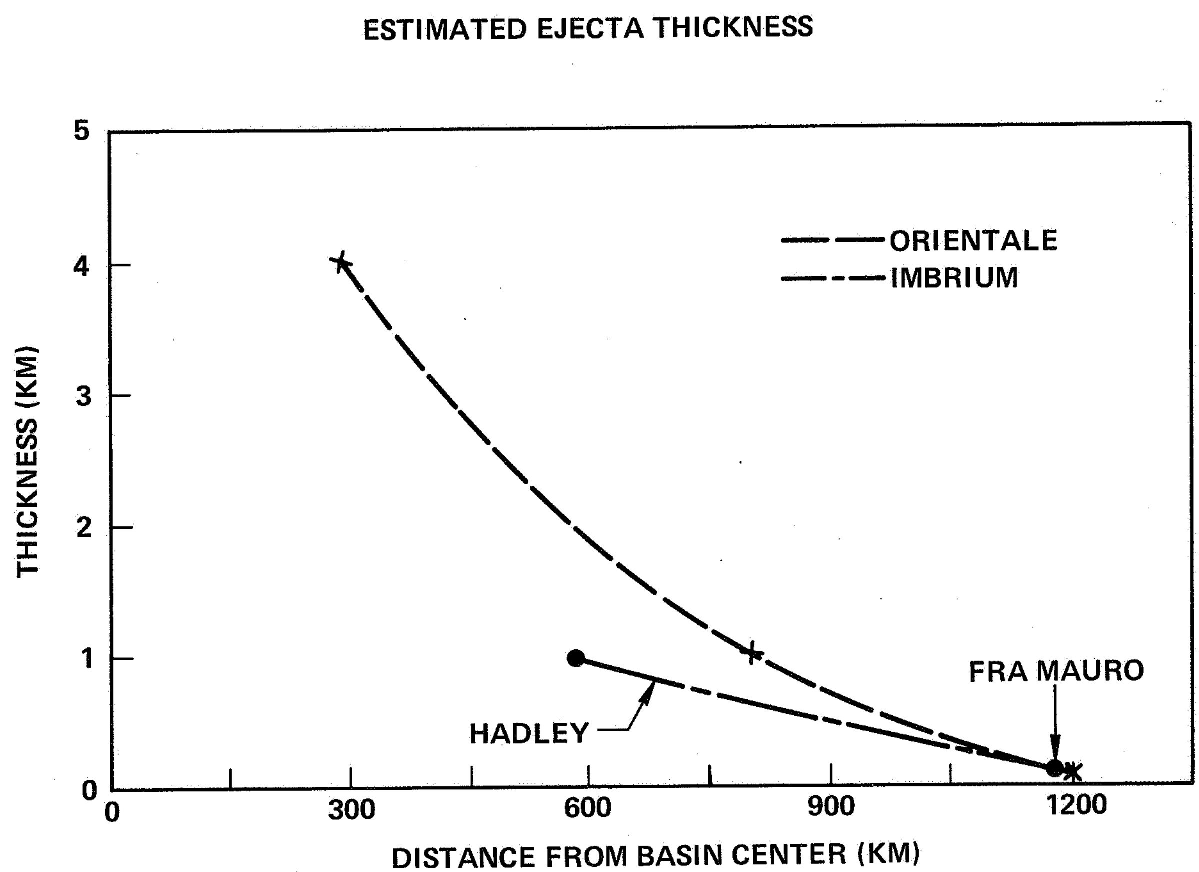

FIGURE 4 - ESTIMATED EJECTA THICKNESS (AFTER EGGLETON)[2]

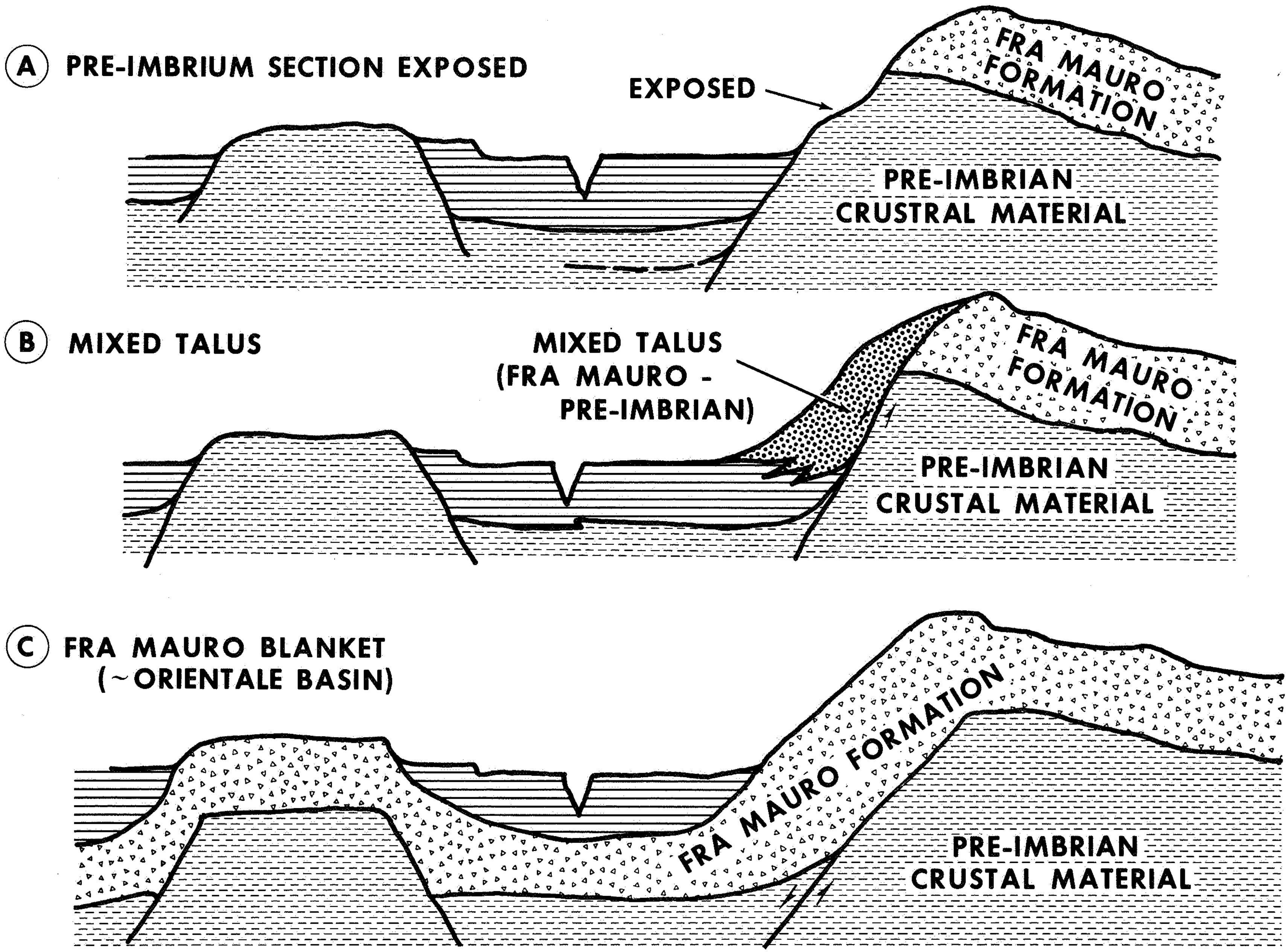

FIGURE 5 POSSIBLE INTERPRETATIONS OF THE APENNINE FRONT

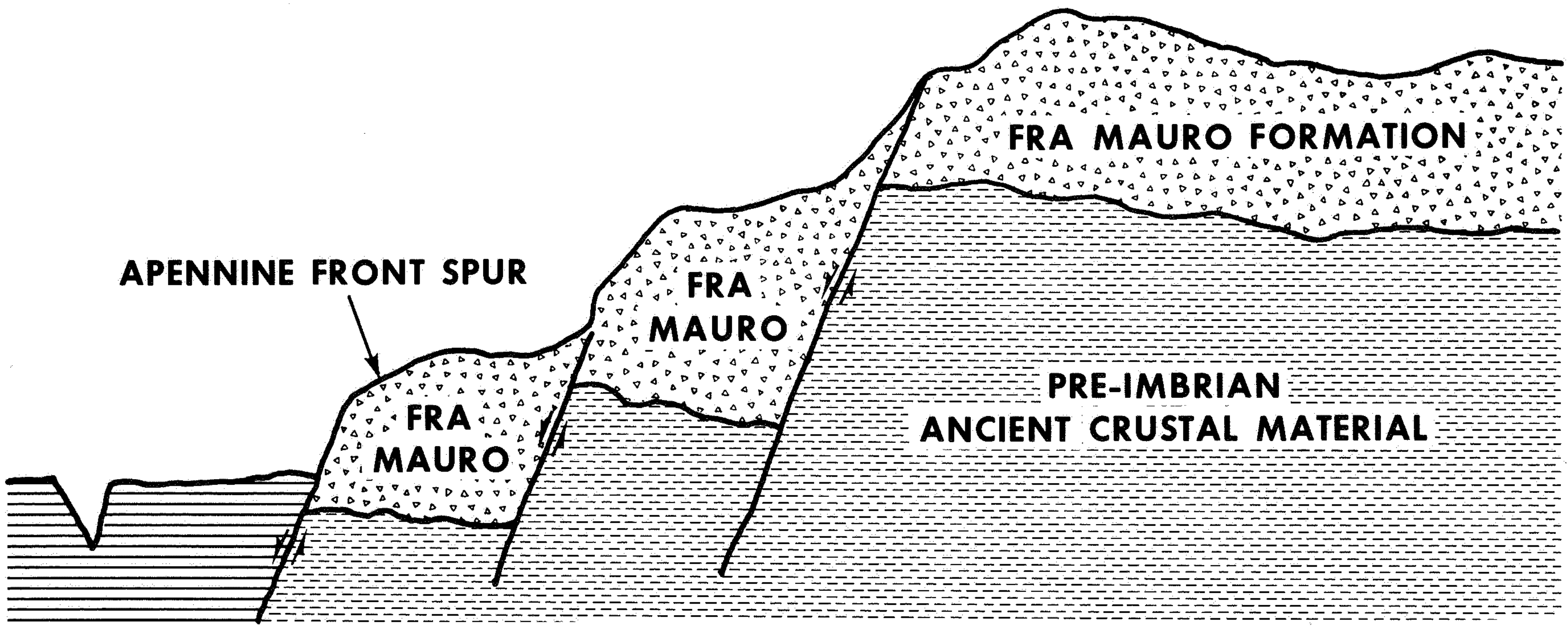

FIGURE 6 POSSIBLE RELATIONSHIP OF APENNINE FRONT SPUR.

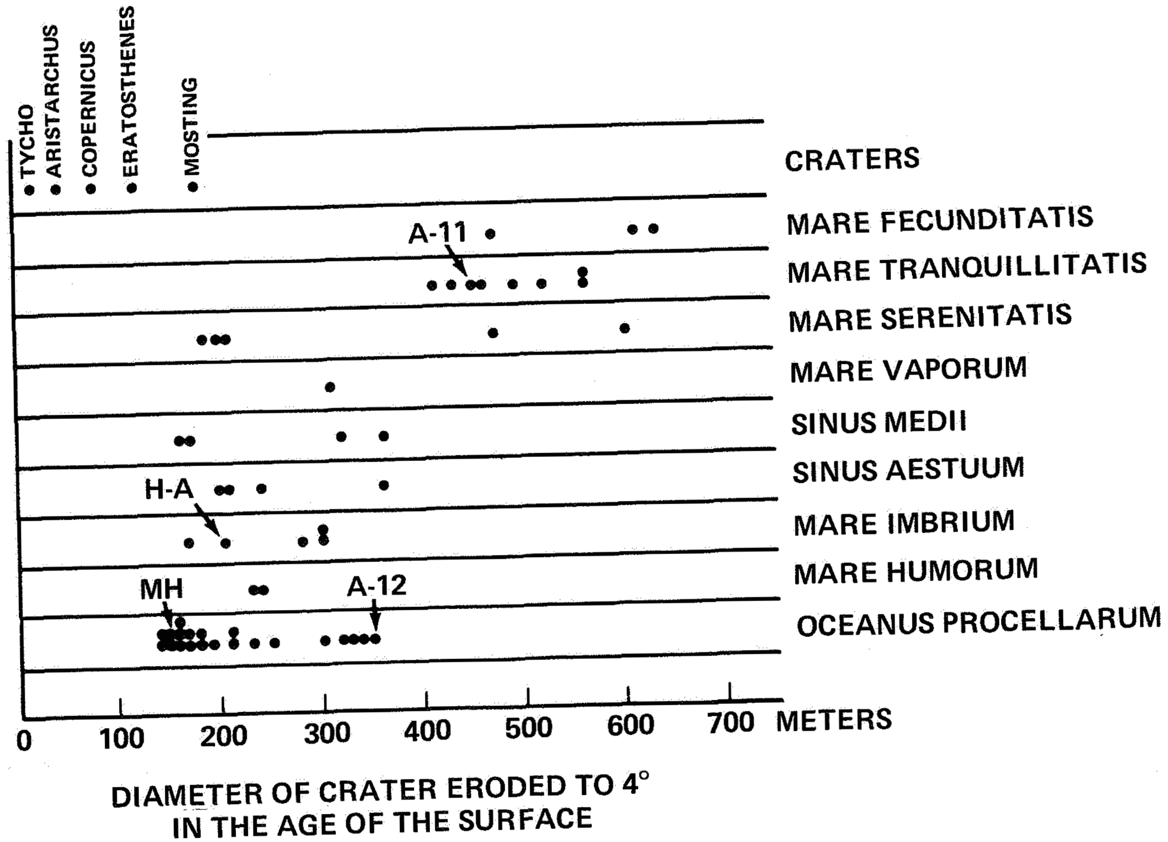

FIGURE 7 - RELATIVE AGES OF MARE UNITS AND MAJOR CRATERS. THE DIAMETER OF A CRATER WHOSE WALLS WOULD BE ERODED TO 4° IN A TIME EQUAL TO THE AGE OF THE SURFACE IS SHOWN FOR EACH AREA STUDIED IN NINE MARE REGIONS. ALSO SHOWN ARE THE RELATIVE AGES OF FIVE MAJOR CRATERS. (SODERBLOM)

SCIENTIFIC OBJECTIVES	SITE 1		SITE 2		SITE 3		SITE 4		SITE 5	
	RIDING	WALKING	RIDING	WALKING	RIDING	WALKING	RIDING	WALKING	RIDING	WALKING
I. APENNINE MOUNTAINS										
A. APENNINE MOUNTAIN FRONT	√	√	—	—	√	—	—	—	?	—
B. APENNINE FRONT SPURS	—	—	—	—	—	—	—	—	√	√
C. APENNINE RIDGE WEST OF RIMA HADLEY	—	—	√	?	—	—	√	?	—	—
II. HADLEY RILLE										
A. RILLE FLOOR	?	—	?	—	—	—	?	—	—	—
B. ELONGATE DEPRESSION	—	—	—	—	—	—	√	?	?	—
C. RILLE WALLS	?	?	√	—	?	?	?	—	?	—
D. RILLE RIM	√	√	√	?	√	√	√	√	√	√
III. MARE MATERIAL										
A. MARE	√	√	√	√	√	√	√	√	√	√
B. SMOOTH PLAINS	—	—	—	—	√	—	—	—	√	√
IV. HADLEY C CRATER										
A. HADLEY C RIM	—	—	√	—	—	—	—	—	—	—
B. HADLEY C OUTER EJECTA	—	—	√	√	?	—	—	—	—	—
V. VOLCANIC LANDFORMS	√	—	—	—	√	—	√	√	√	√
VI. SECONDARY CRATER CLUSTERS	√	√	?	—	?	?	√	—	—	—

FIGURE 8 SCIENTIFIC OBJECTIVES AND SITES-HADLEY/APENNINE REGION

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